Investigation of forming-free resistive switching of nanocrystalline hafnium oxide thin films

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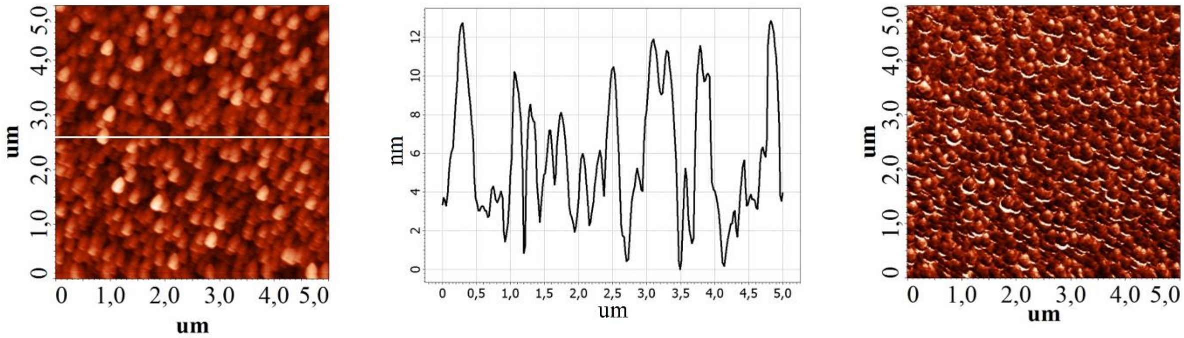
Development of the neuromorphic computer systems is the promising direction of microelectronics, which offers great prospections in unstructured data processing and low power consumption. One of the possible ways of neuromorphic systems is integrated chip (IC) based on neuromorphic structures manufacturing, which are memory elements in the form of cells (neurons) interconnected by data buses (synapses). Such structures can change their electrical resistance between low resistance state (LRS) and high resistance state (HRS) under the influence of an external electric field (effect of resistive switching) and are the basis of non-volatile resistive memory (RRAM) [1-7]. Analysis of the publications showed that films based on binary metal oxides are promising for the manufacture of RRAM [8-10]. Hafnium oxide (HfO_2) is a perspective material, which shows forming-free effect of resistive switching with low power consumption, large HRS/LRS coefficient and high endurance [11-13]. However, for the manufacture of based on forming-free HfO_2 RRAM elements it is necessary to study the regimes of resistive switching in it. Thus, investigation of the effect of resistive switching in HfO_2 films is the aim of this work.

Hafnium oxide thin film was grown using pulsed laser deposition technique. Al_2O_3/TiN as a wafer was used. Deposition performed under the following conditions: wafer temperature: 400°C, target–wafer distance: 50 mm, O_2 pressure: 1 mTorr, pulse energy: 300 mJ. AFM-image of hafnium oxide film surface was obtained using atomic-force microscope Solver P47 Pro (NT-MDT, Russia). Electric measurements were carried out using semiconductor characterization system Keithley 4200-SCS (Keithley, USA) with W probes. During experiment TiN layer was grounded. Current-voltage curves were obtained at –1 to +1 voltage sweep. Using the results obtained, resistance of HfO_2 dependence on number of cycle number (endurance test) was built. Curves analyzing was implemented using Origin 8.1 software.

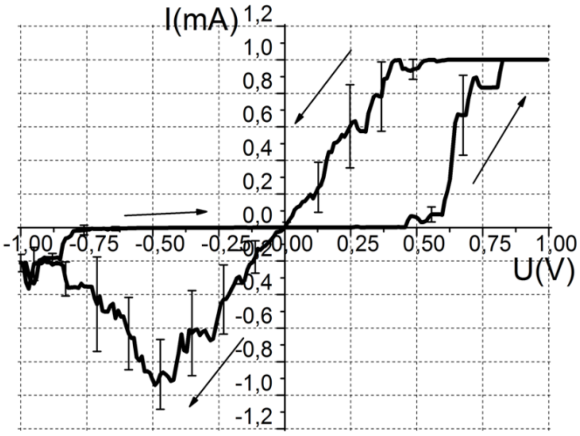
Figure 1 shows experimental investigations of HfO_2 film morphology. It is shown that HfO_2 film surface has a granular structure with 0.25±0.08 μm grain size. The HfO_2 film thickness was measured by scanning of HfO_2/TiN boundary and was equaled 30.25±5.13 nm. Figure 2 shows electric measurements of TiN/HfO_2/W structure. Resistive switching from HRS to LRS (SET) was occurred at 0.62±0.15 V, and from LRS to HRS (RESET) at -0.23±0.04 V. Endurance test shown that HRS was 75.83±20.61 kΩ, LRS was 0.74±0.11 kΩ (Figure 1b). It was shown, that HRS/LRS ratio was about 101 at read voltage 0.15 V.

The results can be useful for based on HfO_2 thin films neuromorphic systems manufacturing.

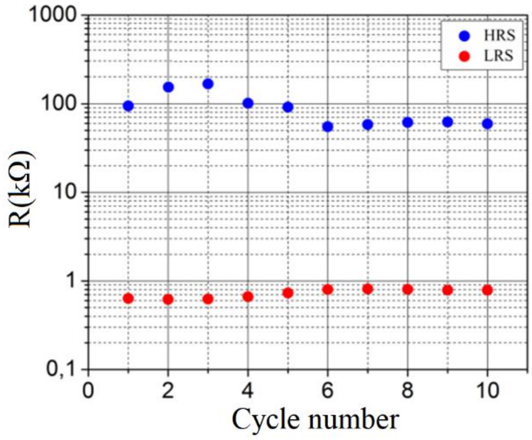


(a) (b) (c)

Figure 1. Investigation of nanocrystalline hafnium oxide film morphology:
(a) AFM-image; (b) cross-section profile along white line on (a); (c) phase.



(a)



(b)

Figure 2. Investigation of effect of resistive switching in forming-free nanocrystalline hafnium oxide film: (a) current-voltage characteristic; (b) endurance test.

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